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Application of Computer Axial Tomography (CAT) to Measuring Crop Canopy Geometry

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16. Abstract Accurate and extensive geometric data of plant canopy structure -- the location and orientation of the foliage -- are surprisingly difficult to obtain but remain a key input to canopy reflectance models. These models are exercised in parameter studies to gain understanding of the potential information in remotely sensed satellite date and thereby address the larger problems of discriminating crops, determining their areal extent, and assessing their physiological condition. Such information is needed to better monitor and manage the worldwide production of several key, economically important crops. Lack of accurate and extensive geometric data has retarded the development and testing of these physically based canopy reflectance models.

To better appreciate the problem of acquiring canopy geometry information, consider the convoluted and time-varying structure of a typical vegetative canopy plus the data requirements of canopy reflectance models. These preclude the adequate measurement of canopy geometric characteristics in a short time period (minutes) using simple measuring tools (meter stick and protractor). To minimally satisfy current modeling requirements, the geometric data are needed as a function of at least two canopy variables, height and the angle from vertical. An additional position variable must be considered to realistically model the reflectance of row crops. The time, azimuth angle, and/or horizontal position are additional variables needed to examine and model the effects of moisture stress, phototropism, and wind upon the canopy reflectance.

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INTRODUCTION

Accurate and extensive geometric data of plant canopy structure - the location and orientation of the foliage - is surprisingly difficult to obtain, but remains a key input to canopy reflectance models. These models are exercised in parameter studies to gain understanding of the potential information in remotely sensed satellite data and thereby address the larger problems of discriminating crops, determining their areal extent, and assessing their physiological condition. Such information is needed to better monitor and manage the world wide production of several key, economically important crops. Lack of accurate and extensive geometric data has retarded the development and testing of these physically based canopy reflectance models.

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OBJECTIVE

An investigation was carried out with the objective of investigating the feasibility of using the principles of computer axial tomography (CAT) to quantify the structure of crop canopies. This was to be achieved through analysis of field data of two economically important crops, corn and soybeans, taking

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into account the convoluted and interwoven foliage in the two canopies. The objective was not the construction of a prototype field data acquisition instrument, but rather, a proof-of-concept demonstration of the applicability of the principles of CAT to the problem of measuring the canopy geometry. Rather than consider adaptation of an x-ray CAT scanner for field use, it was proposed, for reasons of radiation safety and cost, to investigate an optical - instead of x-ray - CAT approach involving photodetectors.

LITERATURE REVIEW

Methods for measuring the structure of a vegetative canopy have necessarily involved simplifying assumptions concerning the canopy, assumptions which effectively reduce its dimensionality and therefore, the complexity of the field measurement task.

Loomis *et al.* (1) used a projection technique and Lang (2) used sequentially an electronic apparatus to determine the area and orientation of each segment of each leaf on a plant. Other methods involve the measurement of gap frequency, a term commonly used in the literature to indicate the probability that a ray of light from above the horizontal will arrive, unattenuated, at a specified location in the canopy. Bonhomme and Chartier (3) used hemispherical photographs, taken with a fisheye lens, to measure gap frequency (see also the review by Anderson)(4). The fisheye lens system is capable of acquiring a large amount of data rapidly in two dimensions, (0,0). Its major disadvantage is the fact that the data is specific to one location and to adequately represent the natural variability of the canopy requires data from many locations. Norman and Tanner (5), Lemeur (6), and other authors used a technique involving a photocell mounted on a horizontal track in a canopy to obtain gap frequency. The output of the photocell was monitored as the cell rapidly traversed the track.

Warren Wilson (7) analyzed canopy structure using the method of inclined point quadrats. The method involves the careful insertion of a pointed needle into the canopy at a particular set of zenith and azimuth angles. Data collection is accomplished by recording the location of each contact of the needle point with foliage. Vanderbilt *et al.* (8) developed a related method in which a narrow laser beam was substituted for the point quadrat needle. Smith and Berry (9) developed an optical diffraction technique for estimating the distribution of foliage angles.

MATERIALS AND METHODS

Healthy, green corn and soybean canopies in the dent and full pod development stages, respectively, were cut with scissors and hedge trimmers on several cross-sections through the foliage. A photograph of each cross-section, representing the intersection

of a plane with the foliage, was enlarged and the air-foliage boundaries, delineated by the plane, were digitized (Figure 1).

For data analysis purposes, a computer program was written and based on the characteristics of a hypothetical field data acquisition system (Figure 2). The hypothetical system consists of an array of photodetectors, each with a field of view delimited to a companion miniature light source located in an array of lights on the opposite side of the canopy cross-section to be measured. The signal from each detector is quantized, 0 (or 1), according to whether foliage does (or does not) block the companion light source. In comparison, the analogous signals from the x-ray detectors in a CAT scanner may have many values, each typically a line integral function of the x-ray density of the material between the x-ray source and detector. For the hypothetical apparatus, the signals from the detectors form a vector representing the projection of the canopy foliage in one direction. By rotating around the canopy, the hypothetical apparatus acquires data at one degree increments through 180 degrees in a sequence similar to that of a CAT scanner.

The computer algorithm used to reconstruct the cross-section of the canopy first duplicates n times each 1 x n vector (n is the number of photo detectors) of data, representing a single projection, to obtain an n x n array. Thus, the 180 vectors are used to generate 180 arrays, each representing a different projection direction through the cross-section of the canopy. In any one array, each row has an identical sequence of ones and zeros and each column contains either all ones or all zeros, depending whether the particular photo detector saw its companion light source through the canopy. There is a one to one mapping of the location of each element in an array to a location in the cross-sectional "slice" of the canopy. Using a nearest neighbor rule, the 180 arrays are overlaid on another array representing the reconstruction of the cross-section of the canopy. The value of a reconstruction array element is the sum of all elements overlaid at the location.

The ocurrance of foliage is indicated by the value of each element of the array representing the canopy cross-section. A zero occupies all those array locations containing foliage; for each location without foliage the reconstruction array contains an integer greater than zero.

RESULTS AND DISCUSSION

Figure 3 shows the corn canopy cross-section reconstructed from projections of the canopy cross-section shown in Figure 1. Figure 3 shows that the algorithm reproduces the round cross-sectional shape of the corn stalk, located some distance from the two corn leaves. Likewise, the convex surfaces of the two leaves are correctly reconstructed.

The algorithm indicates the hollow cupped portion of each leaf is foliage. This is because to outline a foliage cross-section, the approach depends upon detection of light rays which just graze the foliage surface, and these rays are blocked by the adjacent concave foliage surface. X-ray CAT scanners are able to accurately reproduce concave shapes because, unlike the case of light interacting with foliage, x-rays do penetrate the material being measured without significant scattering out of the beam.

Current canopy reflectance models don't require geometry data at the high spatial resolution shown in Figure 3. While the nature of the optical CAT system proposed here does require that the data be acquired at high resolution, that resolution may be easily degraded subsequently to obtain any desired lower resolution. At the lower resolutions more suitable to reflectance modeling activities, the need to reconstruct concave foliage surfaces is obviated because once the resolution cell includes the entire surface, calculation of the projected leaf area is simple. Alternatively, for each low resolution cell, the actual leaf area might be calculated following appropriate processing to correctly identify the air-foliage interfaces.

Figure 3 belies the importance of measuring a canopy cross-section sparsely populated with foliage. Any foliage in the cross-section blocks in some direction the view of any other piece of foliage in the cross-section. Thus, foliage shapes in a densely populated cross-section would tend to be poorly resolved. These considerations may limit application of this technique to sparsely foliaged canopies such as corn, sorghum, wheat, barley, and sunflowers. The technique may not provide satisfactory results for such densely foliaged canopies as alfalfa and soybeans.

It may be difficult to construct and use an optical CAT system to measure sections of such canopies as corn which may have plants three meters tall and rows 0.75 meters wide. The device would be a leviathan. However, all is not lost because it is probably possible to successfully characterize the geometric characteristics of such a plant canopy by extrapolation from measurements of individual plants, provided the plants retain their geometric properties. It would be necessary to accurately measure the locations of plants in the canopy. Then the geometric characteristics of a hypothetical canopy would be computed after populating it with the characteristics of plants randomly selected from the pool of measured plants. Measurement of the canopy geometry characteristics, one plant at a time, might be feasible for such crops as corn, sorghum, sunflowers. For wheat and barley, small clumps of plants, all the tillers from one seed for example, might be measured.

CONCLUSIONS

The application of an optical computer axial tomography (CAT) system to measuring crop canopy geometry was investigated. The approach shows promise of being able to provide needed canopy geometric information for input data to canopy reflectance models. The difficulty of using an optical CAT scanner to measure large canopies of crops like corn was discussed and a solution proposed involving the measurement of plants one at a time.

ACKNOWLEDGEMENTS

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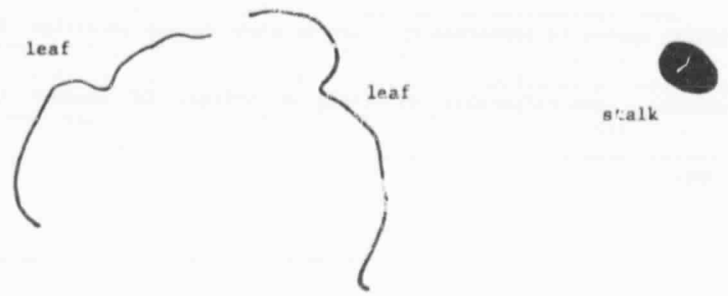

Figure 1. Cross-section of corn canopy.

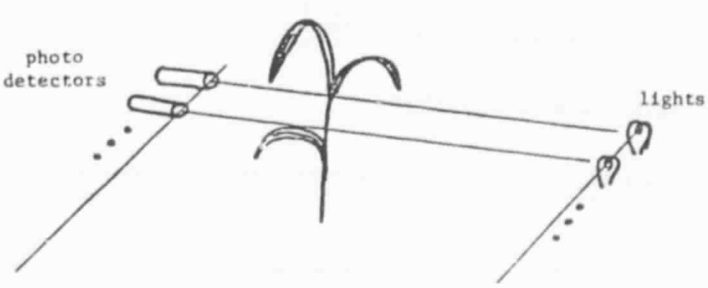

Figure 2. Conceptual design of optical CAT system.

Figure 3. Reconstructed corn canopy cross-section.